Herbicide Effects on Tensile Strength and Rooting of Centipedegrass Sod

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Abstract. "Effects of selected herbicides on sod tensile strength and rooting of mature and immature turf of common centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack] were studied in field experiments. Herbicides evaluated were atrazine, atrazine + tridiphane, bensulide, DCPA, DPX-6316, imazapyr, imazaquin, napropamide, oxadiazon, pendimethalin, sethoxydim, simazine, and sulfometuron. At 2, 4, and 8 weeks after treatment (WAT), sod tensile strength was determined, and root length and number were measured 7 to 10 days later. In 1986 sod tensile strength was not affected, but in 1987 the tensile strength of the immature turf was reduced at 8 WAT by bensulide and imazapyr. Rooting was suppressed most by bensulide, imazapyr, napropamide, and sulfometuron at most rates and dates tested. By 8 WAT, root length, root number, and tensile strength of herbicide-treated centipedegrass sod did not differ from that of the untreated sod except for those plots treated with bensulide or imazapyr. Chemical names used: 6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine (atrazine); 2-(3,5-dichlorophenyl)-2-(2,2,2-trichloroethyl) oxirane (tridiphane); O,O'-bis(1-methylethyl)S-[2-[(phenylsulfonyl) amino] ethyl] phosphorodithioate (bensulide); dimethyl-2,3,5,6-tetrachloro-1,4-benzenedicarboxylate (DCPA); methyl 3-[[[4-methoxy-6-methyl-1,3,5-triazin-2-ylaminocarbonyl]aminosulfonyl]-2-thiophenecarboxylate (DPX-6316); (&)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid (imazapyr); 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid (imazaquin); N,N-diethyl-2-(1-naphthalenylloxy)propanamide (napropamide); 3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one (oxadiazon); N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine (pendimethalin); 2-[1-(ethoxymino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one (sethoxydim); 6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine (simazine); 2-[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl] benzoic acid (sulfometuron).

In commercial sod production, a weed-free uniform stand of sod is desired. The value and tensile strength of the sod are reduced by weed infestation. Herbicides are generally used for weed control in sod production. The effect of many herbicides on rooting and tensile strength of sod is unknown.

Considerably more research has dealt with tensile strength and rooting of cool-season than of warm-season turfgrasses. Troutman and Jagschitz (1971) showed that the tensile strength of immature Kentucky bluegrass (*Pea pratensis* L.) sod was decreased up to 5 months after treatment with bensulide. Clipping yields of fine fescue (*Festuca rubra* L.) were reduced by bensulide applications (Turgeon et al., 1974). DCPA, but not bensulide, reduced rooting of *Poa* species (Turgeon, 1972). Shearman et al. (1979) found

bensulide applications, to either the sodbed or the sod, suppressed rooting of transplanted Kentucky bluegrass sod. Jagschitz (1977) showed herbicides inhibited rooting more when they were applied near the time of transplanting.

Research in Alabama showed that increasing atrazine levels linearly reduced tensile strength of centipedegrass sod (Turner and Dickens, 1987). Coats (1975) found DCPA suppressed rooting of centipedegrass up to 21 days after treatment, and simazine and atrazine reduced both stolon survival and growth. Single or repeat applications of atrazine or simazine were found to impair the establishment of centipedegrass in Georgia (Johnson, 1973). Troutman et al. (1974), however, found that neither root nor shoot growth of centipedegrass was reduced by either DCPA or simazine. Johnson (1975) reported that oxadiazon at 3.4 kg/ha did not reduce the establishment of centipedegrass, which also has been shown to be tolerant of sethoxydim (Johnson, 1987).

The objective of this study was to determine the effects of selected herbicides on tensile strength and rooting ability of common centipedegrass sod.

Experiments were conducted on a sod farm in Macon County, Ala., on a mature turf of common centipedegrass in 1986 and an immature turf in 1987 produced on Leaf silt

loam (clayey, mixed, thermic Typic Albicquilt). Mature turf had 100% ground cover and tensile strength adequate for harvesting and handling, while the immature turf had 100% ground cover but lacked adequate tensile strength for harvesting. Soil pH values were 5.2 and 5.6 for the 1986 and 1987 sites, respectively, and P (17 ppm) and K (76 ppm) levels were moderate and high, respectively (Cope et al., 1980), at both experiment sites. No additional P, K, or lime was required according to soil test recommendations (Cope et al., 1980). Nitrogen was applied monthly at a rate of 0.24 kg/100 m² in early May, June, July, and August, and water was applied with a center-pivot system as needed to prevent stress. The turfs were mowed weekly with a reel mower at 3.8 cm and the clippings were returned to the surface.

A randomized complete-block design was used with 1.8 × 3.7-m plots replicated four times. A single application of the herbicides (Table 1) at a spray volume of 225 liter/ha⁻¹ and at 150 kPa pressure was made 25 June 1986 and 12 June 1987.

Injury ratings were determined visually on 7 Aug. 1986 (6 weeks after application) and 30 June 1987 (3 weeks after application).

Two 2000-cm² blocks of sod were harvested from each plot 2, 4, and 8 weeks after the application of the herbicides (WAT) for determination of sod tensile strength. Tensile

Table 1. Injury to common centipedegrass from herbicide applications during 1986 and 1987 in Macon County, Ala.

Herbicide	Rate (kg/ha ⁻¹)	Injury ^z (%)	
		1986	1987
Atrazine	2.2	0 c ^y	0 f
	3.4	0 c	0 f
Atrazine + tridiphane	2.2	0 c	0 f
	0.56		
Atrazine + tridiphane	3.4	0 c	0 f
	0.56		
Bensulide	13.5	0 c	5 ef
DCPA	13.5	0 c	3 f
DPX-6316	0.03	0 c	0 f
	0.07	0 c	0 f
Imazapyr	0.07	93 a	46 b
	0.12	91 a	59 ab
	0.25	89 a	66 a
Imazaquin	0.28	0 c	0 f
	0.41	0 c	3 f
	0.56	0 c	5 ef
Napropamide	2.2	0 c	1 f
	4.5	0 c	0 f
Oxadiazon	2.2	0 c	21 cd
	4.5	0 c	71 a
Pendimethalin	1.7	0 c	1 f
	3.4	0 c	0 f
Sethoxydim	0.28	0 c	0 f
	0.56	0 c	1 f
Simazine	2.2	0 c	0 f
	3.4	3 b	0 f
Sulfometuron	0.01	0 c	0 f
	0.03	0 c	0 f
	0.07	0 c	1 f
Untreated	---	0 c	0 f

^yTurf injury ratings were made 6 WAT in 1986 and 3 WAT in 1987 based on a percentage scale of 0 = no injury, 100 = all plants dead. Values are means of four replications.

^zMeans within a column marked with the same letter are not different at $P \leq 0.05$.

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Table 2. Herbicide effects on tensile strength of common centipedegrass sod.

		Tensile strength (kg)					
		1986			1987		
Herbicide	Rate (kg·ha ⁻¹)	Weeks after treatment					
		2	4	8	2	4	8
Atrazine	2.2	17.6 a-e ^z	19.1 a-d	28.1 a-d	16.6 a-d	14.9 b-g	11.7 c-g
	3.4	16.4 a-c	21.1 ab	23.1 a-d	16.9 a-d	14.6 b-g	17.0 a-g
Atrazine + tridiphane	2.2	16.6 a-c	16.0 a-c	28.5 a-d	19.5 a-d	20.5 ab	13.4 b-g
	0.56						
Atrazine + tridiphane	3.4	16.3 a-c	16.7 a-c	24.6 a-d	17.7 a-d	15.1 b-g	13.1 b-g
	0.56						
Bensulide	13.5	22.5 ab	18.8 a-d	22.4 bcd	18.6 a-d	14.0 c-g	11.2 d-g
DCPA	13.5	21.1 abc	16.3 a-c	31.8 ab	22.7 a	11.7 fg	16.1 a-g
DPX-6316	0.03	15.0 a-c	18.6 a-d	24.0 a-d	17.2 a-d	16.5 a-g	15.7 a-g
	0.07	14.7 a-c	15.2 a-c	25.2 a-d	16.0 a-d	16.3 a-g	17.6 a-f
Imazapyr	0.07	---	---	---	20.7 a-d	15.3 a-g	10.1 fg
	0.12	15.3 a-c	10.9 de	17.2 de	19.8 a-d	14.9 b-g	10.3 c-g
	0.25	17.8 a-c	15.4 a-e	17.3 de	20.5 a-d	13.9 d-g	9.8 g
Imazaquin	0.28	16.6 a-c	14.9 a-c	20.6 b-c	16.3 a-d	20.2 abc	19.3 abc
	0.41	11.7 de	11.0 cde	18.9 cde	22.3 ab	21.2 a	22.9 a
	0.56	15.2 a-c	17.7 a-d	25.8 a-d	20.1 a-d	14.5 b-g	18.5 a-d
Napropamide	2.2	17.2 a-c	19.2 a-d	26.4 a-d	14.2 cd	10.9 g	14.6 b-g
	4.5	20.4 a-c	19.8 abc	25.4 a-d	19.2 a-d	12.5 fg	16.4 a-g
Oxadiazon	2.24	16.3 a-c	20.3 ab	25.6 a-d	15.9 a-d	14.3 b-g	17.9 a-c
	4.5	16.0 a-c	14.7 b-c	27.9 a-d	16.2 a-d	15.4 a-g	14.0 b-g
Pendimethalin	1.7	15.1 a-e	15.0 a-e	26.2 a-d	18.3 a-d	13.2 efg	13.9 b-g
	3.4	20.7 a-d	19.4 a-d	30.2 abc	19.0 a-d	19.7 a-d	13.9 b-g
Sethoxydim	0.28	23.1 a	23.6 a	34.8 a	15.4 a-d	12.0 fg	13.0 b-g
	0.56	15.1 a-e	17.2 a-e	20.2 b-e	16.4 a-d	15.1 b-g	15.4 b-g
Simazine	2.2	22.8 a	19.5 a-d	27.4 a-d	13.5 d	10.4 g	12.0 b-g
	3.4	11.6 c	14.2 b-c	20.0 b-e	15.7 a-d	15.0 b-g	17.1 a-g
Sulfometuron	0.01	13.2 cde	14.7 b-c	20.6 b-e	19.8 a-d	15.5 a-g	15.9 a-g
	0.03	19.0 a-c	16.3 a-c	27.6 a-d	21.2 a-d	15.0 b-g	15.9 a-g
	0.07	16.9 a-c	17.0 a-c	30.9 abc	15.0 bcd	17.9 a-f	15.4 b-g
Untreated	---	20.0 a-c	15.7 a-e	27.3 a-d	16.4 a-d	19.1 a-c	19.4 ab

^zMeans within a column marked with the same letter are not different at $P \leq 0.05$.

Data are means of eight observations.

strengths were based on sod samples with a width of 30.5 cm. The tensile strength of the sod was measured on a conventional sod-strength table (Mitchell and Dickens, 1979), using a load cell to express tension in terms of voltage transmitted through an analog-digital converter to a portable computer programmed to continuously sample incoming data and record the highest value obtained.

A single 1000-cm³ block of sod from each plot was harvested at the time of the tensile strength determination and transported to Auburn Univ. Turfgrass Research Unit at Auburn. Sod blocks were subdivided into three subsamples and randomly placed on washed mortar sand contained in above-ground beds 15 cm deep and lined with 0.15 mm (6mil) polyethylene and equipped with drains to remove excess water. These blocks were maintained under cyclic irrigation to stimulate root initiation.

After 7 to 10 days the beds were flooded to facilitate removal of the sod from the sand bed with roots intact. Root densities were determined by randomly placing three rings, each enclosing an area of 15.2 cm², on the inverted sod and counting the number of roots enclosed by each ring. Values for individual rings were treated statistically as sub-samples. The lengths of the five longest roots occurring on each subsample were recorded and the values pooled as subsamples for analysis.

Data were subjected to analysis of variance and treatment means separated using Duncan's multiple range test, where $P = 0.05$.

Imazapyr was the only herbicide to cause serious injury to the turf in 1986, although simazine at 3.4 kg·ha⁻¹ produced slight visible injury 6 WAT (Table 1). In 1987, imazapyr- and oxadiazon-treated sod showed injury 3 WAT. Injury from imazapyr increased steadily and killed all aerial shoots of the turf 4 to 8 weeks later.

In 1986, tensile strength measured 2, 4, and 8 WAT showed that none of the herbicide treatments had a deleterious effect on mature turf (Table 2). Even the sod seriously injured by imazapyr maintained tensile strength throughout the entire 8-week evaluation period. Sod treated with sethoxydim at 0.28 kg·ha⁻¹ and simazine at 2.2 kg·ha⁻¹ had tensile strengths superior to several other treatments during this period. At 4 and 8 WAT, sethoxydim at 0.28 kg·ha⁻¹ continued to produce tensile strengths superior to those obtained from certain rates of imazapyr, simazine, imazaquin, oxadiazon, or sulfometuron.

In 1987, at 2 WAT, none of the herbicide treatments had reduced tensile strength of the sod below that of the untreated control. DCPA-treated sod had a higher tensile strength than did sod treated with the lower rates of simazine and napropamide and the highest

rate of sulfometuron. Sod treated with simazine at 2.2 kg·ha⁻¹ had the lowest numerical tensile strength at 2 WAT. At 4 WAT, napropamide, sethoxydim at 0.28 kg·ha⁻¹, simazine at 2.2 kg·ha⁻¹, and DCPA reduced tensile strength of the sod below that of the untreated control. At 8 WAT, only bensulide and imazapyr decreased the tensile strength stall levels evaluated. At 8 WAT, sod treated with imazaquin at 0.41 kg·ha⁻¹ had a tensile strength superior to sod receiving certain levels of atrazine, bensulide, imazapyr, napropamide, oxadiazon, pendimethalin, sethoxydim, simazine, and sulfometuron, while the lower or higher levels of imazaquin did not.

In 1986, at 2 WAT, atrazine at 3.4 kg·ha⁻¹, bensulide, imazapyr, napropamide, and sulfometuron at 0.07 kg·ha⁻¹ had decreased root numbers in centipedegrass sod below those of the untreated control (Table 3). At 4 WAT, bensulide, imazapyr, and napropamide at 4.5 kg·ha⁻¹ continued to suppress the number of roots produced. At 8 WAT, only sod treated with bensulide or imazapyr at 0.25 kg·ha⁻¹ showed reduced root numbers.

In 1987, at 2 WAT, the bensulide, imazapyr, napropamide, oxadiazon, pendimethalin, simazine, and sulfometuron treatments reduced the number of roots produced. However, by 4 WAT, this effect was no longer discernible, possibly due to the large variation among the samples ($cv = 62\%$). Bensulide and imazapyr treatments at

Table 3. Herbicide effects on root number of common centipedegrass sod.

		Root no./100 cm ²					
		1986			1987		
		Weeks after treatment					
Herbicide	Rate (kg·ha ⁻¹)	2	4	8	2	4	8
Atrazine	2.2	42.1 d-h ^a	54.6 bc	35.5 abc	61.2 a-e	41.4 a-g	85.5 ab
	3.4	40.1 e-h	55.2 bc	32.2 bcd	50.0 cde	32.9 a-h	80.2 ab
Atrazine + tridiphane	2.2	51.3 b-f	55.2 bc	44.7 abc	54.6 a-e	37.5 a-g	69.1 abc
	0.56						
Atrazine + tridiphane	3.4	63.1 a-e	63.8 b	39.5 abc	52.6 b-e	42.7 a-f	70.4 abc
	0.56						
Bensulide	13.5	2.6 jk	2.6 d	2.6 de	3.9 h	5.3 hi	15.8 ef
DCPA	13.5	52.0 b-f	59.8 bc	35.5 abc	65.8 a-d	40.8 a-g	66.4 bc
DPX-6316	0.03	51.3 b-f	88.8 b	42.1 abc	39.5 def	33.5 a-h	76.3 abc
	0.07	63.1 a-e	73.7 b	53.3 abc	78.9 ab	40.1 a-g	82.2 ab
Imazapyr	0.07	---	---	---	0.0 h	0.2 i	28.3 de
	0.12	0.0 k	1.3 d	46.0 abc	0.0 h	0.0 i	5.9 ef
	0.25	0.0 k	0.0 d	2.6 de	1.6 h	0.0 i	0.1 f
Imazaquin	0.28	50.0 b-f	82.2 b	65.8 ab	59.8 a-c	40.8 a-g	82.9 ab
	0.41	80.9 a	125.0 a	68.4 a	73.0 abc	52.0 abc	86.8 ab
	0.56	54.6 b-e	86.2 b	63.8 abc	51.3 cde	54.6 ab	92.7 ab
Napropamide	2.2	27.6 f-i	63.1 b	36.2 abc	1.3 h	10.5 ghi	70.4 abc
	4.5	5.3 ijk	25.0 cd	30.3 cd	9.2 gh	14.5 e-i	91.4 ab
Oxadiazon	2.2	63.1 a-e	77.6 b	41.4 abc	38.8 def	49.3 a-d	68.4 abc
	4.5	68.4 abc	89.4 b	62.5 abc	2.6 h	25.0 b-i	76.3 abc
Pendimethalin	1.7	52.0 b-f	58.5 bc	36.8 abc	34.2 efg	27.0 b-i	73.0 abc
	3.4	44.1 c-g	61.8 b	39.5 abc	17.1 fgh	12.5 f-i	48.7 cd
Sethoxydim	0.28	59.8 a-e	70.4 b	40.1 abc	80.9 a	53.3 abc	84.8 ab
	0.56	61.8 a-c	74.3 b	53.9 abc	52.0 b-e	46.0 a-e	82.2 ab
Simazine	2.2	51.3 b-f	63.1 b	34.2 abc	44.7 de	36.2 a-h	68.4 abc
	3.4	70.3 ab	83.5 b	42.1 abc	37.5 ef	49.3 a-d	92.7 ab
Sulfometuron	0.01	52.0 b-f	82.2 b	63.1 abc	2.9 gh	53.9 ab	75.0 abc
	0.03	25.0 g-j	80.9 b	34.2 bc	0.2 h	19.1 d-i	65.1 bc
	0.07	18.4 h-k	61.8 b	46.0 abc	0.0 h	21.7 c-i	64.5 bc
Untreated	---	67.1 a-d	80.2 b	58.5 abc	74.3 abc	23.0 b-i	71.7 abc

^aMeans within a column marked with the same letter are not different at $P \leq 0.05$. Data are means of 12 observations.

Table 4. Herbicide effects on root length of common centipedegrass sod.

		Root length (cm)					
		1986			1987		
Herbicide	Rate (kg·ha ⁻¹)	Weeks after treatment					
		2	4	8	2	4	8
Atrazine	2.2	8.0 abc ^z	13.2 ab	6.6 ab	4.7 a-d	5.4 abc	11.5 a
	3.4	8.1 abc	11.9 ab	6.5 ab	3.8 a-c	5.3 abc	11.4 a
Atrazine + tridiphane	2.2	9.8 a	12.3 ab	7.4 ab	4.3 a-c	5.0 abc	11.2 a
	0.56						
Atrazine + tridiphane	3.4	7.6 abc	10.7 bc	6.8 ab	3.9 a-c	5.9 ab	11.4 a
	0.56						
Bensulide	13.5	2.5 ef	3.3 ef	4.1 bc	0.7 e	1.6 e	5.4 c
DCPA	13.5	9.5 e	14.1 ab	7.4 ab	5.4 ab	5.2 abc	10.9 a
DPX-6316	0.03	7.9 abc	14.2 ab	9.0 a	4.3 a-c	5.9 ab	12.1 a
	0.07	9.3 a	13.8 ab	9.2 a	5.5 a	5.4 abc	12.2 a
Imazapyr	0.07	---	---	---	0.0	2.1 de	7.6 b
	0.12	1.5 f	0.8 f	7.1 ab	0.0	0.0	3.6 c
	0.25	0.0	0.0	2.2 c	1.1 cde	0.0	3.4 c
Imazaquin	0.28	8.1 abc	13.0 ab	7.2 ab	3.5 a-e	5.7 abc	12.3 a
	0.41	9.6 a	13.8 ab	8.7 a	4.5 a-e	5.9 ab	11.5 a
	0.56	7.6 abc	11.7 ab	8.8 a	3.9 a-c	6.3 ab	11.6 a
Napropamide	2.2	6.6 a-d	11.9 ab	7.0 ab	0.9 de	4.9 abc	11.1 a
	4.5	4.1 def	8.0 cd	6.5 ab	1.4 b-c	4.3 a-e	11.8 a
Oxadiazon	2.2	9.5 a	14.1 ab	7.8 ab	3.6 a-e	5.4 abc	11.1 a
	4.5	9.9 a	13.8 ab	7.3 ab	1.5 a-c	5.3 abc	11.6 a
Pendimethalin	1.7	8.3 abc	12.9 ab	7.3 ab	3.3 a-e	4.5 a-d	11.6 a
	3.4	8.8 ab	12.4 ab	7.4 ab	2.3 a-e	2.9 cde	10.0 ab
Sethoxydim	0.28	9.7 a	13.4 ab	6.4 ab	5.2 ab	5.9 ab	12.2 a
	0.56	8.3 abc	13.6 ab	9.1 a	3.6 a-e	5.5 abc	11.0 a
Simazine	2.2	8.8 ab	13.5 ab	6.8 ab	3.7 a-e	5.4 abc	11.8 a
	3.4	8.6 ab	14.0 ab	7.4 ab	3.1 a-c	6.2 ab	12.0 a
Sulfometuron	0.01	5.4 b-e	13.8 ab	8.5 a	2.0 a-c	7.2 a	12.1 a
	0.03	4.7 c-f	10.6 bc	7.0 ab	0.8 de	6.3 ab	11.1 a
	0.07	4.1 def	12.0 ab	6.7 ab	0.0	6.0 ab	9.7 ab
Untreated	---	9.1 a	13.8 ab	8.6 a	4.9 abc	3.6 b-e	11.4 a

^aMeans within a column marked with the same letter are not different at $P < 0.05$. Data are means of 12 observations.

8 WAT again showed significantly reduced root numbers.

In general, the effects of herbicides on root length were similar to their effects on root number. In 1986, at 2 WAT, root lengths were reduced by bensulide, imazapyr, napropamide at 4.5 kg·ha⁻¹, and sulfometuron treatments (Table 4). By 4 WAT, only bensulide, imazapyr, and napropamide at 4.5 kg·ha⁻¹ continued to reduce root length; sulfometuron-treated sod no longer had reduced root length. At 8 WAT, napropamide at 4.5 kg·ha⁻¹ had ceased to affect root length, but bensulide and imazapyr continued to suppress root elongation.

In 1987, bensulide, imazapyr, and napropamide at 2.2 kg·ha⁻¹, and sulfometuron at 0.03 and 0.07 kg·ha⁻¹ had reduced root length by 2 WAT. At 4 WAT, none of the herbicide treatments could be shown to reduce root length, possibly due to the large variation among the samples (cv = 36%). At 8 WAT, bensulide and imazapyr were the only herbicide treatments that still reduced root length of the sod.

The results indicate that neither mature nor immature sod will exhibit visible effects from any of the herbicides at 8 WAT, except imazapyr, which had killed the aerial portion of the sod completely by that time. None of the herbicides reduced tensile strength of mature centipedegrass sod, and only imazapyr and bensulide affected strength of immature sod when applied after spring growth was well under way. However, results might be quite different if the same herbicides were applied in early spring, before centipedegrass has fully recovered from winter dormancy.

Although many of the herbicides causing reduced root length and/or number also visibly injured the turfgrass, the degree of injury was not consistent with respect to the degree of damage to rooting or tensile strength. However, since salability of sod is affected materially by the aesthetic quality of the top growth, visible injury may make certain herbicides unacceptable for use in sod production. Imazapyr and bensulide caused visible injury and/or reduced rooting enough to preclude their use on centipedegrass sod within 8 weeks before expected harvest.

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Respiratory Rates and Glycosidase Activities of Juice Vesicles Associated with Section-drying in Citrus

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Abstract. Oxygen uptake and glycosidase activities were examined in normal and granulated juice vesicles of several citrus fruit. Oxygen uptake was low in normal juice vesicles isolated from freshly harvested 'Lee' tangelos [*Citrus reticulata* Blanco cv. Clementine × (*Citrus paradisi* Macf. cv. Duncan × *Citrus reticulata* Blanco cv. Dancy)] and stored 'Dancy' tangerine (*C. reticulata* Blanco) and 'Marsh' grapefruit (*Citrus paradisi* Macf.) (35.7, 17.9, and 11.6 μl O₂/hr per g fresh weight, respectively), but was 2- to 3-fold higher in granulated juice vesicles. As severity of granulation increased in grapefruit, O₂ uptake increased. Oxygen uptake in normal and disordered juice vesicles of all citrus fruit examined was reduced to nondetectable levels with 0.1 mM KCN and was insensitive to salicylhydroxamic acid. α- and β-galactosidase and α- and β-glucosidase activities were present in extracts of normal grapefruit juice vesicles (123, 214, 51, and 25 nmol·hr⁻¹·g⁻¹ fresh weight, respectively) and was 2- to 3-fold higher in extracts of granulated tissue. α- and β-mannosidase activities, nondetectable in normal juice vesicle extracts, were present in extracts from granulated tissue. The results suggest that increased metabolic activity occurs in granulated juice vesicles and the energy produced may be used to support cell wall synthesis and modification. Increases in O₂ uptake and glycosidase activities correlate well with observed symptoms of section-drying in citrus.

Section-drying is a late-harvest physiological disorder of citrus fruit, such as 'Valencia' orange (Bartholomew et al., 1941) and many tangerine and grapefruit cultivars (Nakajima, 1976; Burns and Achor, 1989). The disorder is characterized by the hardening, or granulation, of the juice vesicles at the stem and/or the stylar end of the fruit segment. In grapefruit, affected vesicles eventually discolor and collapse. In some cases, vesicles may collapse without undergoing granulation. Section-drying can occur in fruit that remain on the tree late in the season,

but becomes more severe during storage of late-harvest fruit. Some cultivars, such as 'Lee' tangelos, can often show symptoms of section-drying before optimum maturity is attained.

Anatomical investigations have shown extensive cell wall thickening and scattered secondary wall formation in internal parenchyma and epidermal cells of granulated juice vesicles isolated from late-harvest citrus fruit (Burns and Achor, 1989; Shomer et al., 1989). Lignin deposition within cells of granulated vesicles has also been detected histochemically in grapefruit (Burns and Achor, 1989), as well as chemically in pummelo (Shomer et al., 1989). Loss of soluble sugars and acidity occurs in juice vesicles associated with granulation (Bartholomew et al., 1941; Sinclair and Jolliffe, 1961; Gilfillan and Stevenson, 1977; El-Zeftawi, 1978; Shomer et al., 1989). A decrease in the

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